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(54) MAGNETIC FIELD SENSORS HAVING STRAY FIELD REJECTION

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CPC ***G01R 33/0017*** (2013.01); ***G01R 33/07*** (2013.01)

(58) **Field of Classification Search**
CPC G01R 33/0017; G01R 33/0029; G01R 15/185
See application file for complete search history.

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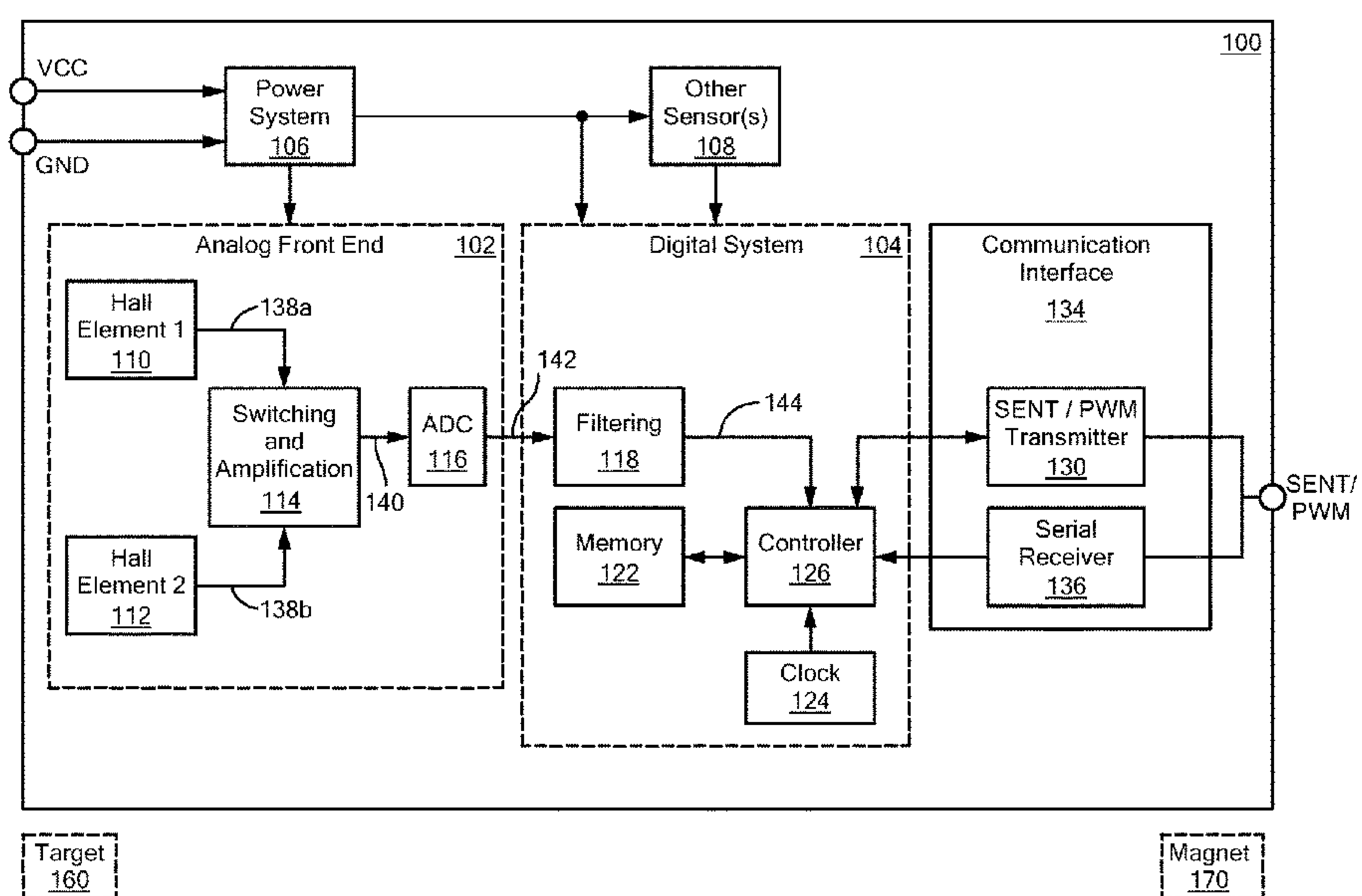
(57) **ABSTRACT**

Described embodiments provide a magnetic field sensor that includes first and second spaced magnetic field sensing elements that each generate a signal indicative of a magnetic field associated with a target. A switching module couples a first terminal of the first magnetic field sensing element having a first polarity to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity to generate a first combined signal. The switching module couples a second terminal of the first magnetic field sensing element having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing element having the first polarity to generate a second combined signal. The switching module simultaneously couples the first and the second combined signals to an amplifier, which generates an output signal indicative of the magnetic field that has stray magnetic field effects cancelled.

19 Claims, 6 Drawing Sheets



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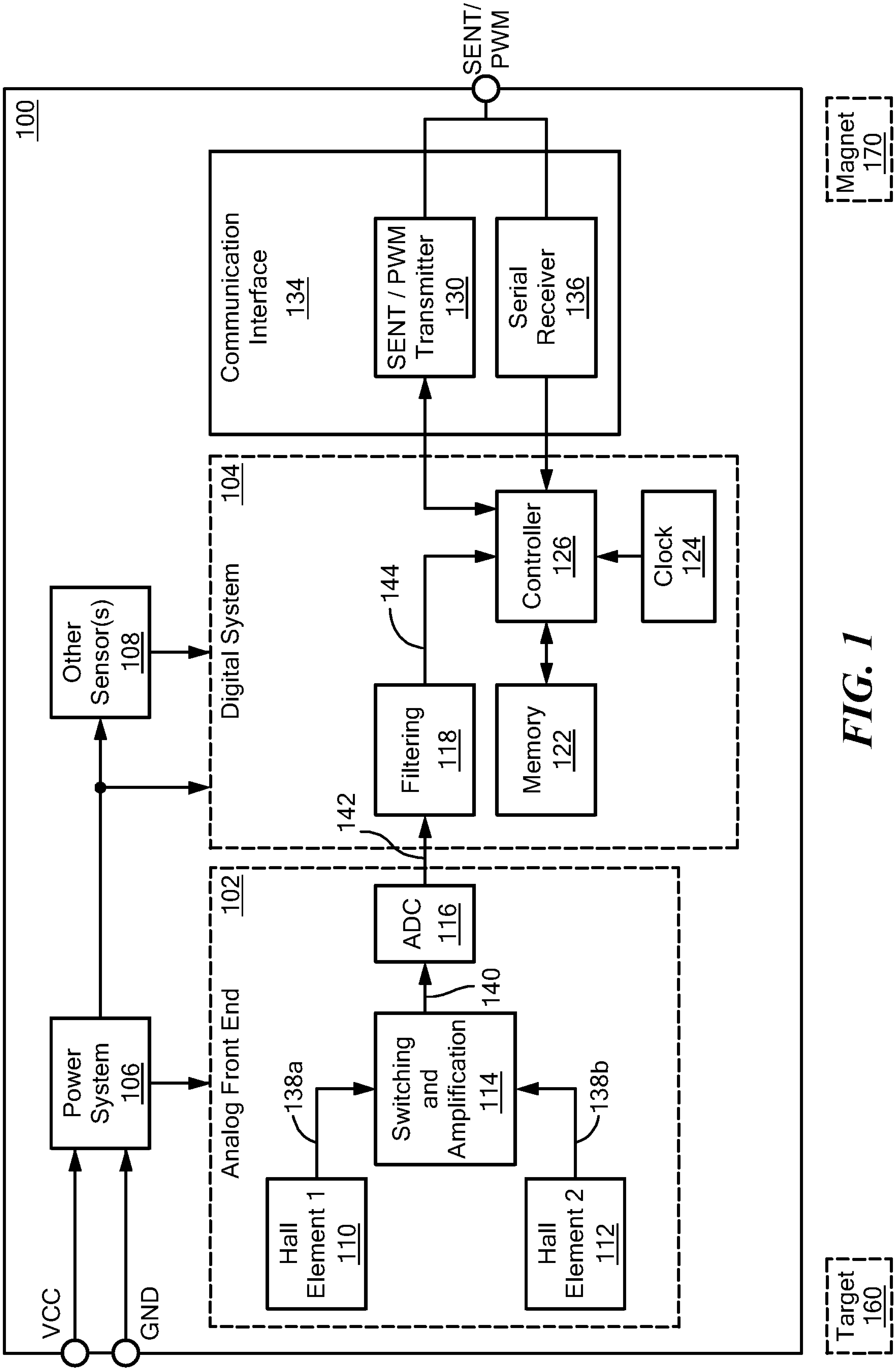

SENT/ PWM
100
Communication Interface 134
SENT / PWM Transmitter 130
Serial Receiver 136
Other Sensor(s) 108
Digital System 104
Controller 126
Clock 124
Memory 122
Filtering 118
144
142
ADC 116
102
140
Analog Front End
Power System 106
Switching and Amplification 114
138a
138b
Hall Element 1 110
Hall Element 2 112
VCC
GND
Magnet 170
Target 160

FIG. 1

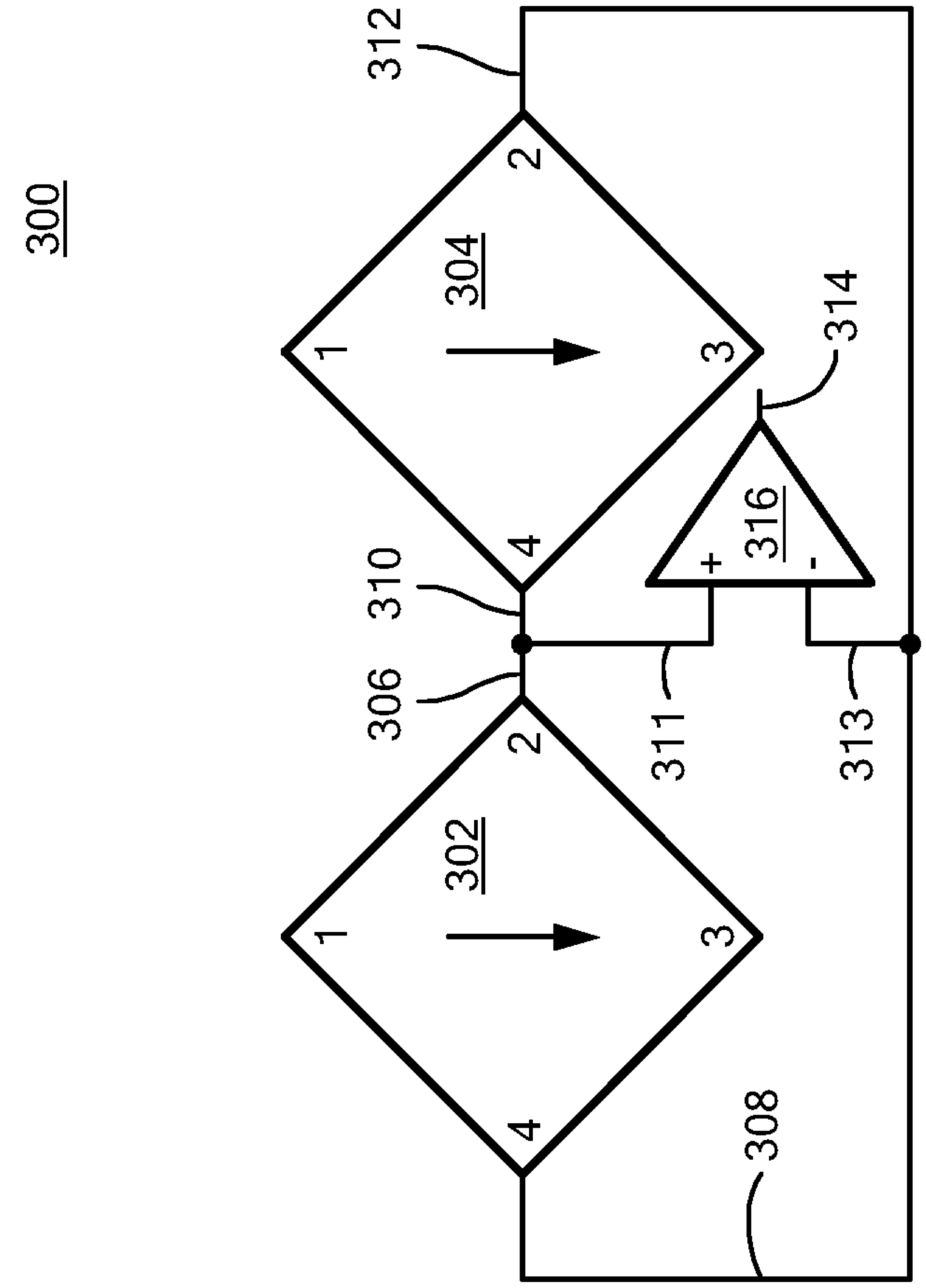


FIG. 3

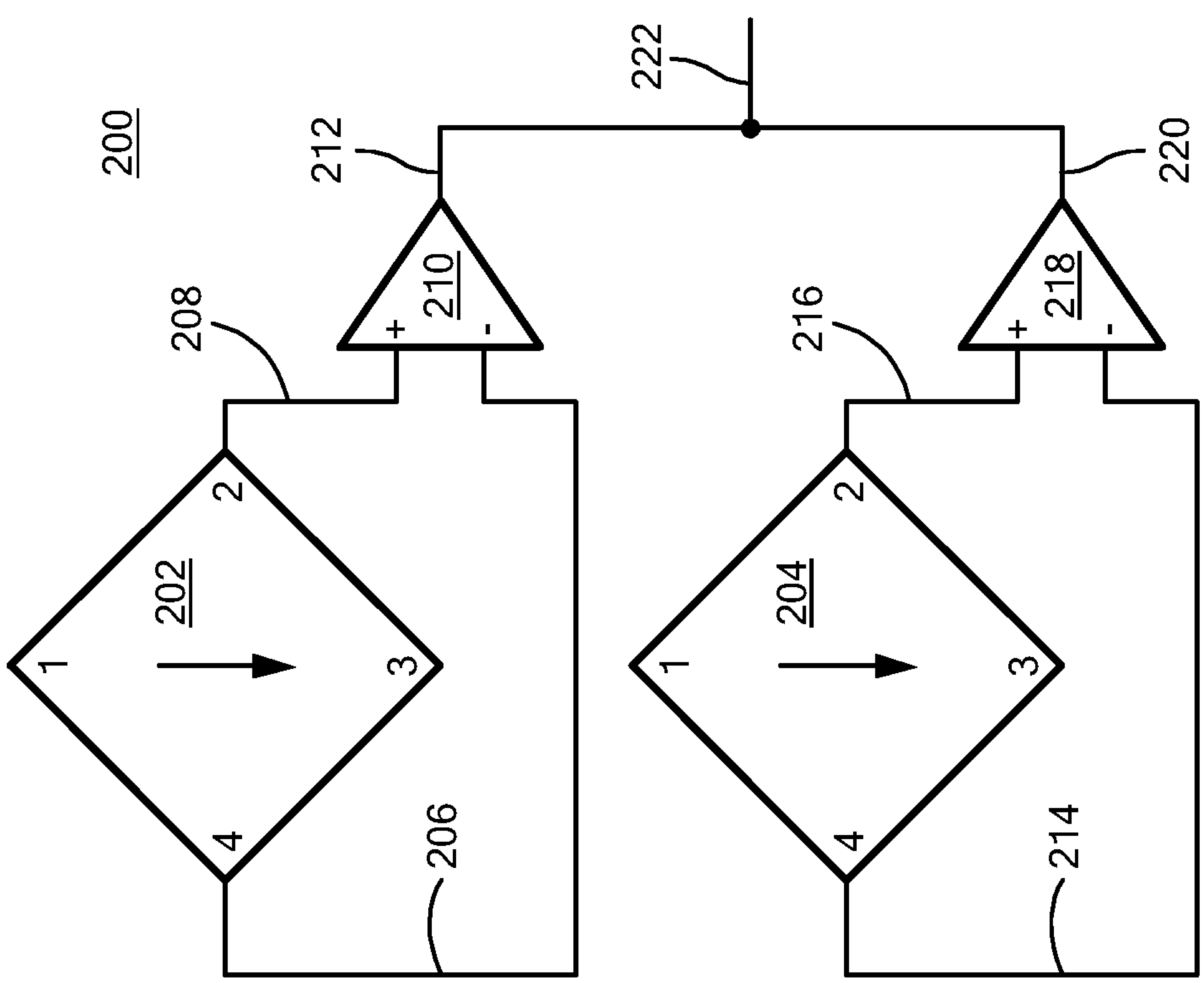
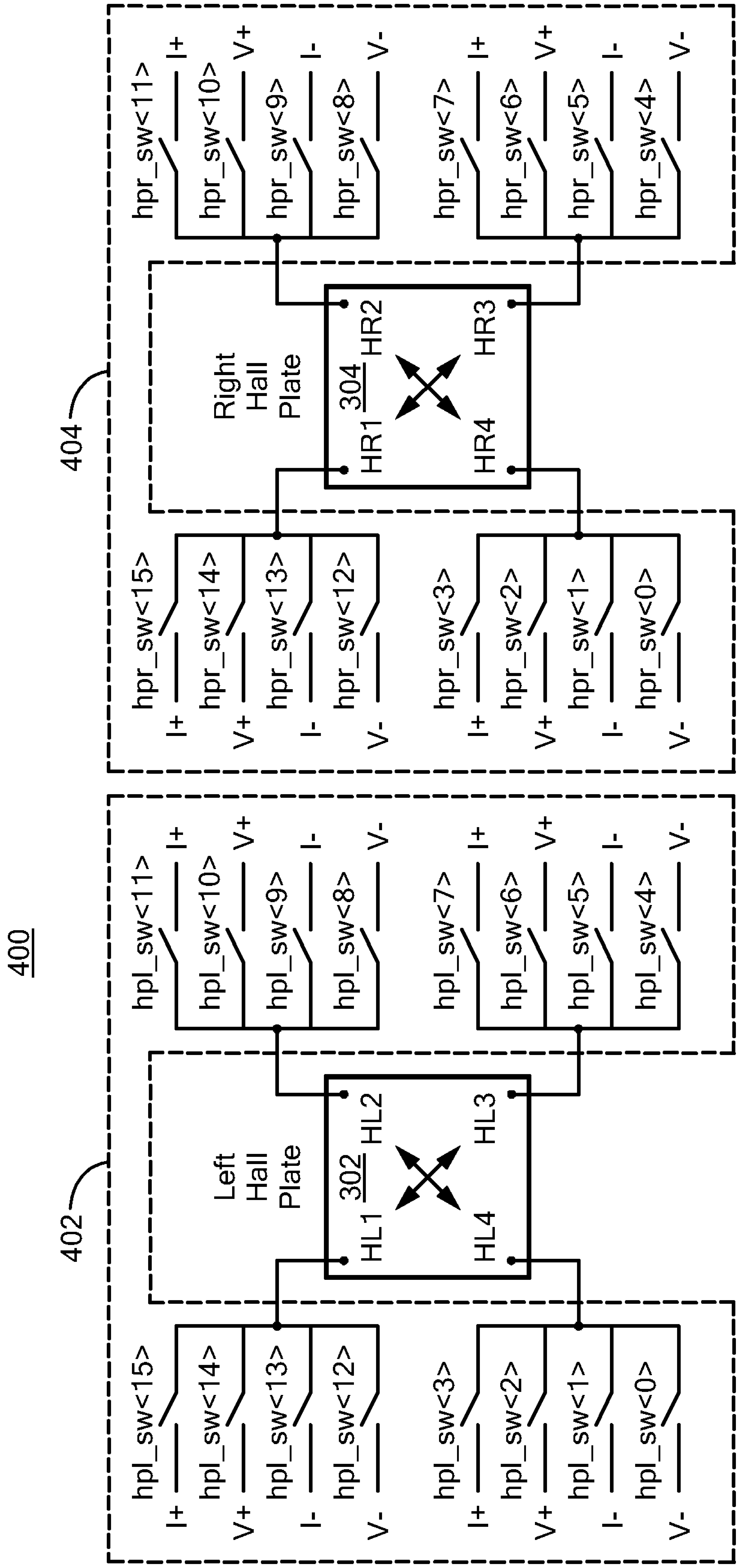


FIG. 2
PRIOR ART



400
402
404
Left Hall Plate
302
HL1
HL2
HL3
HL4
Right Hall Plate
304
HR1
HR2
HR3
HR4
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hpl_sw<1>
hpl_sw<2>
hpl_sw<3>
hpl_sw<4>
hpl_sw<5>
hpl_sw<6>
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hpr_sw<9>
hpr_sw<10>
hpr_sw<11>
hpr_sw<12>
hpr_sw<13>
hpr_sw<14>
hpr_sw<15>
I+
V+
I-
V-

FIG. 4

FIG. 5A

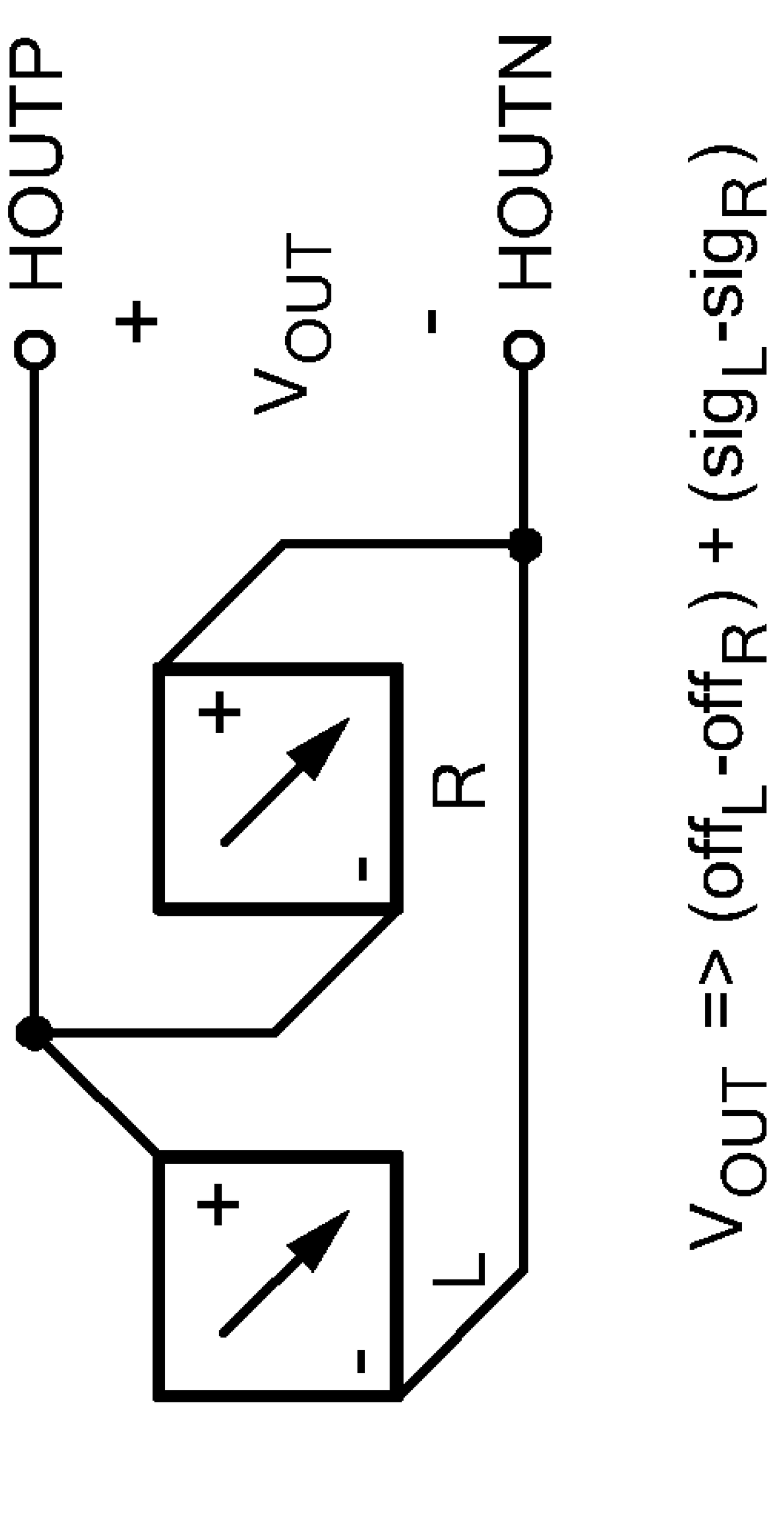


FIG. 5B

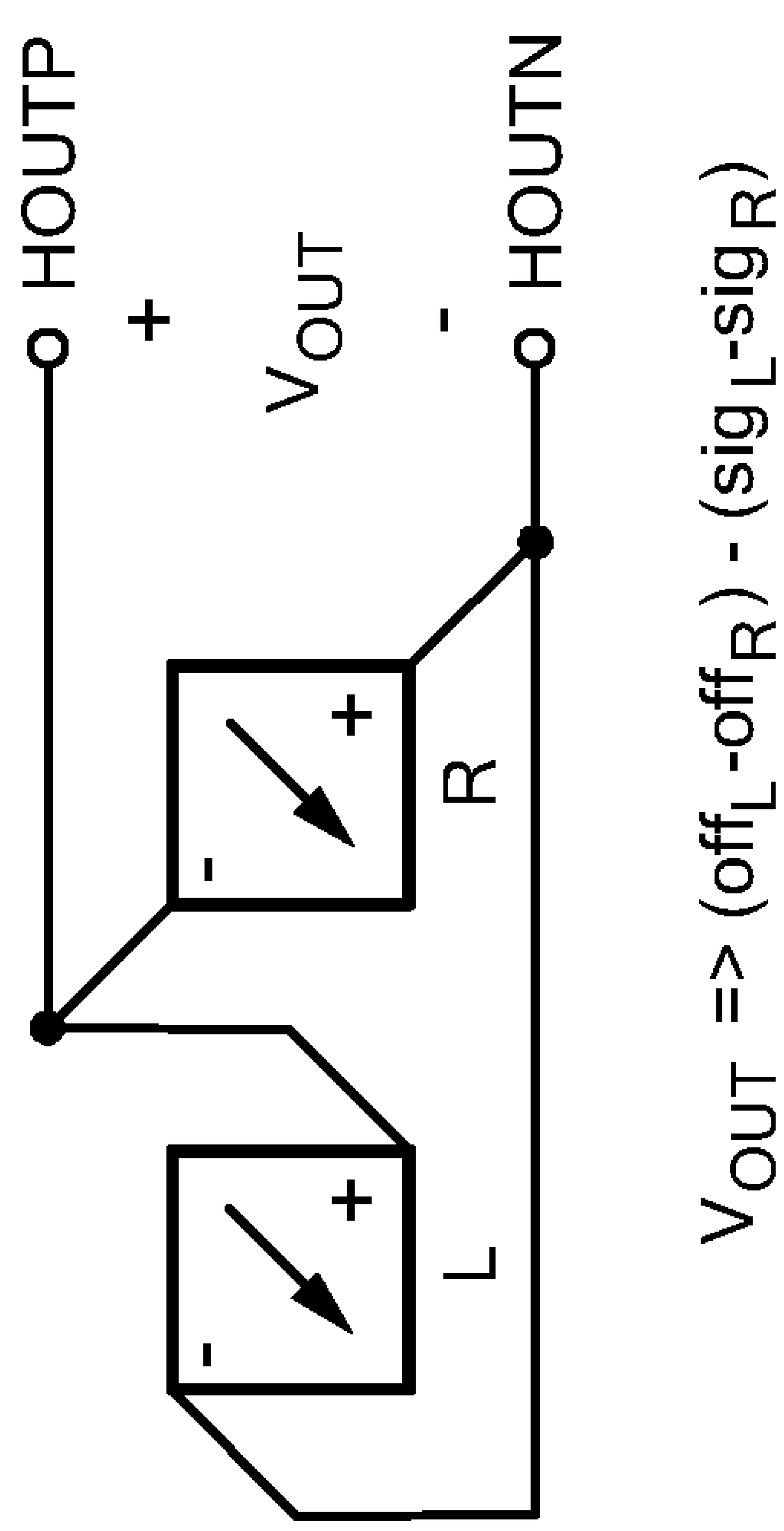


FIG. 5C

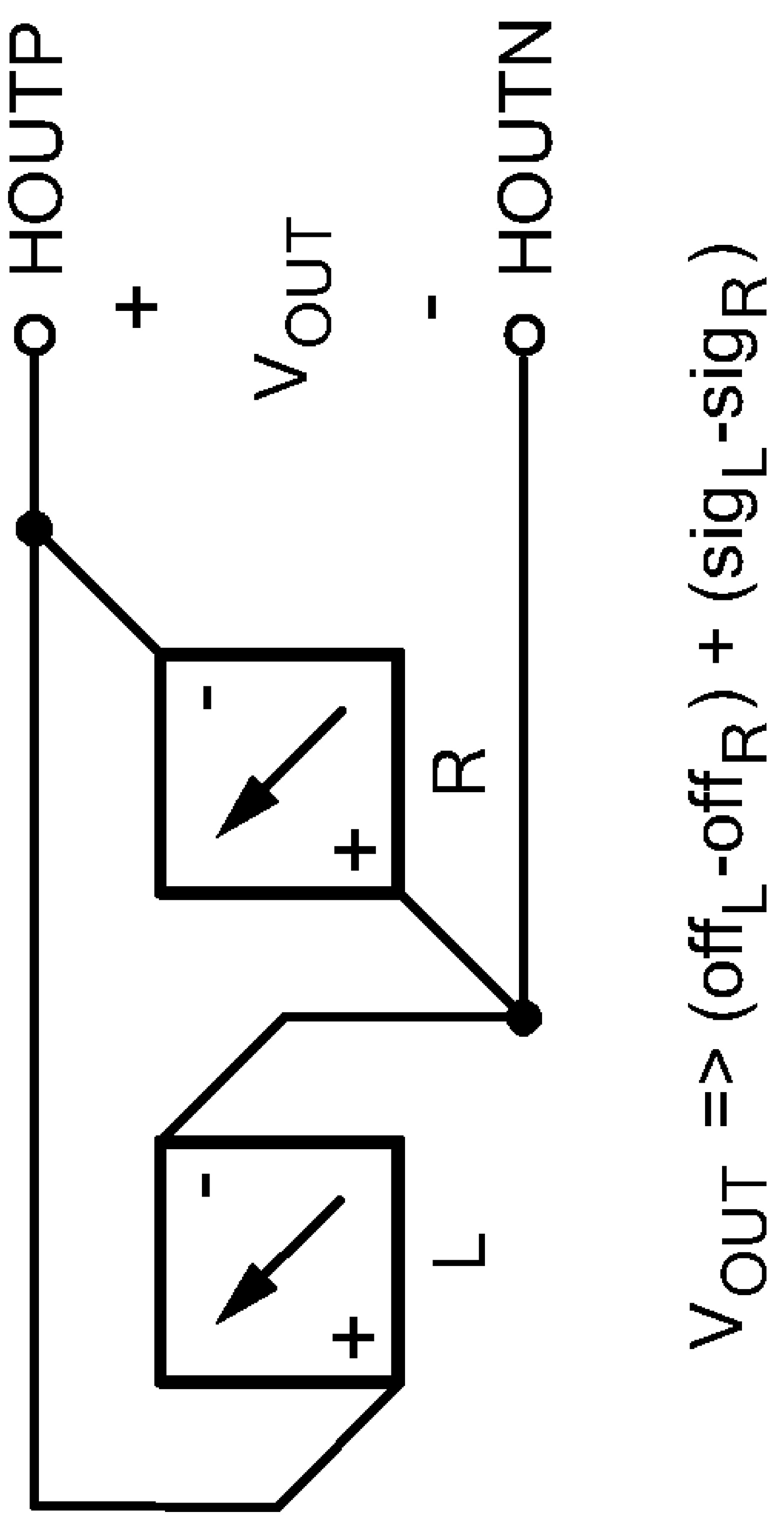
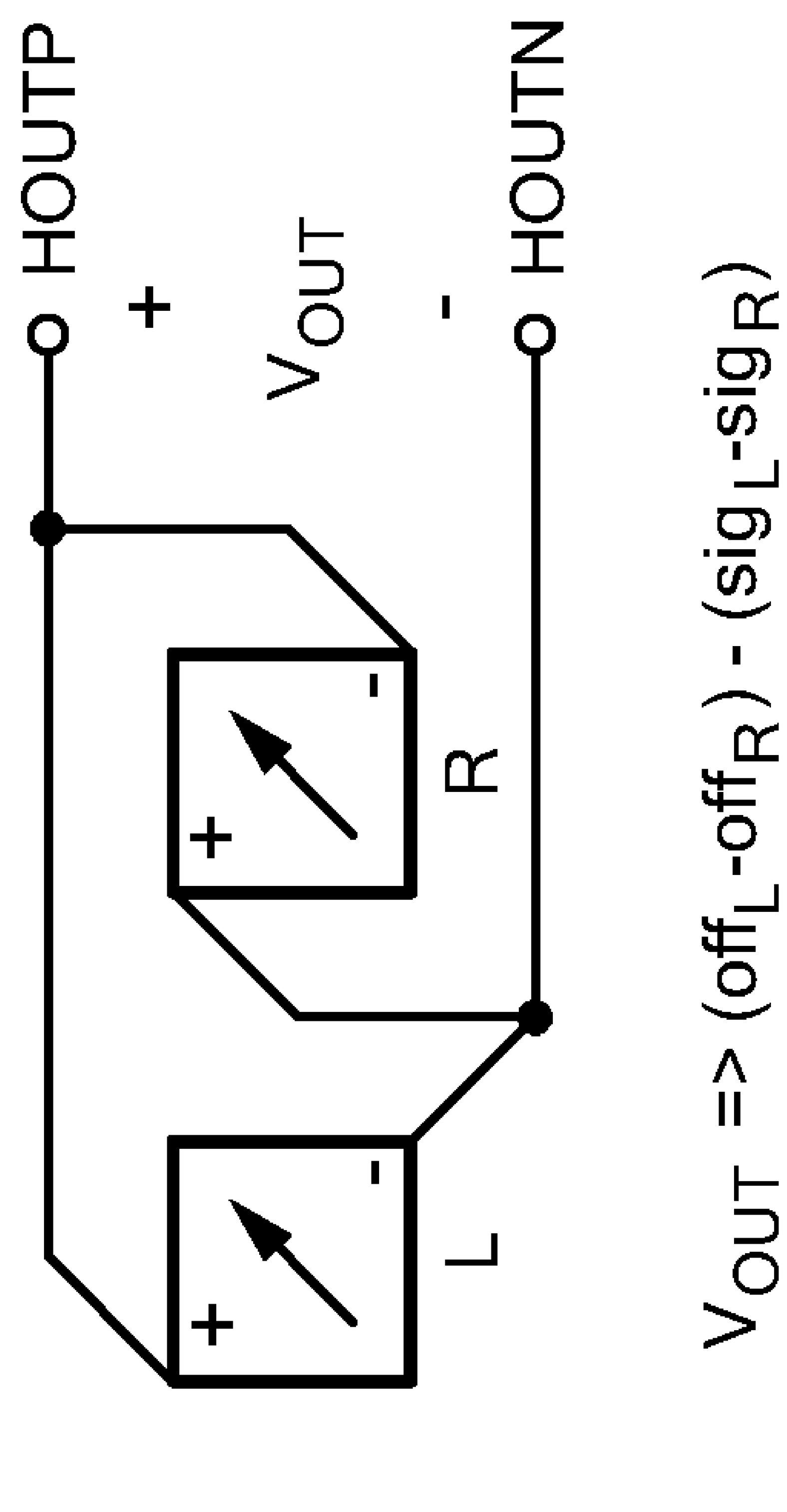


FIG. 5D



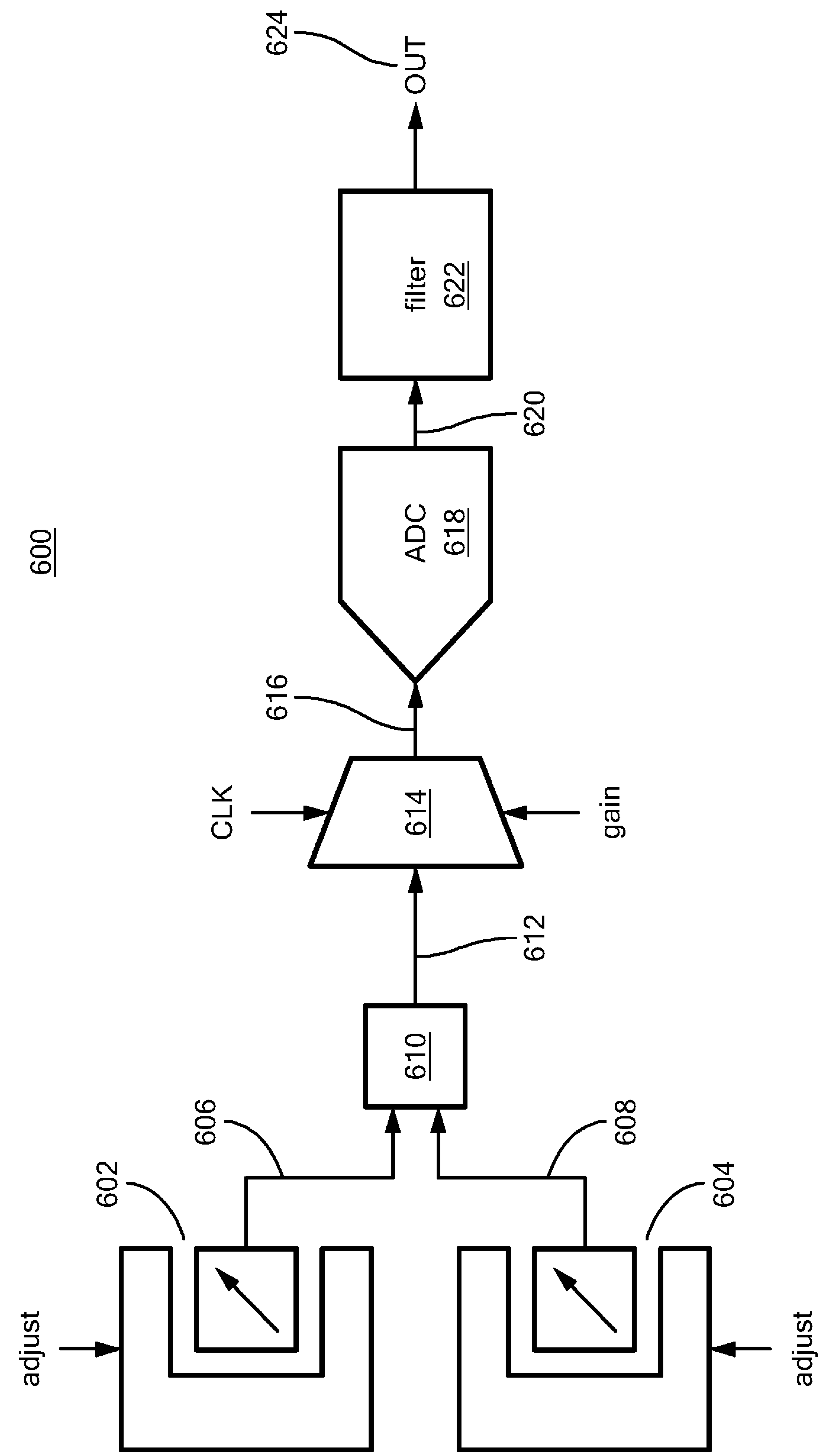

600
624
OUT
filter
622
620
ADC
618
616
CLK
614
gain
612
610
606
608
602
604
adjust
adjust

FIG. 6

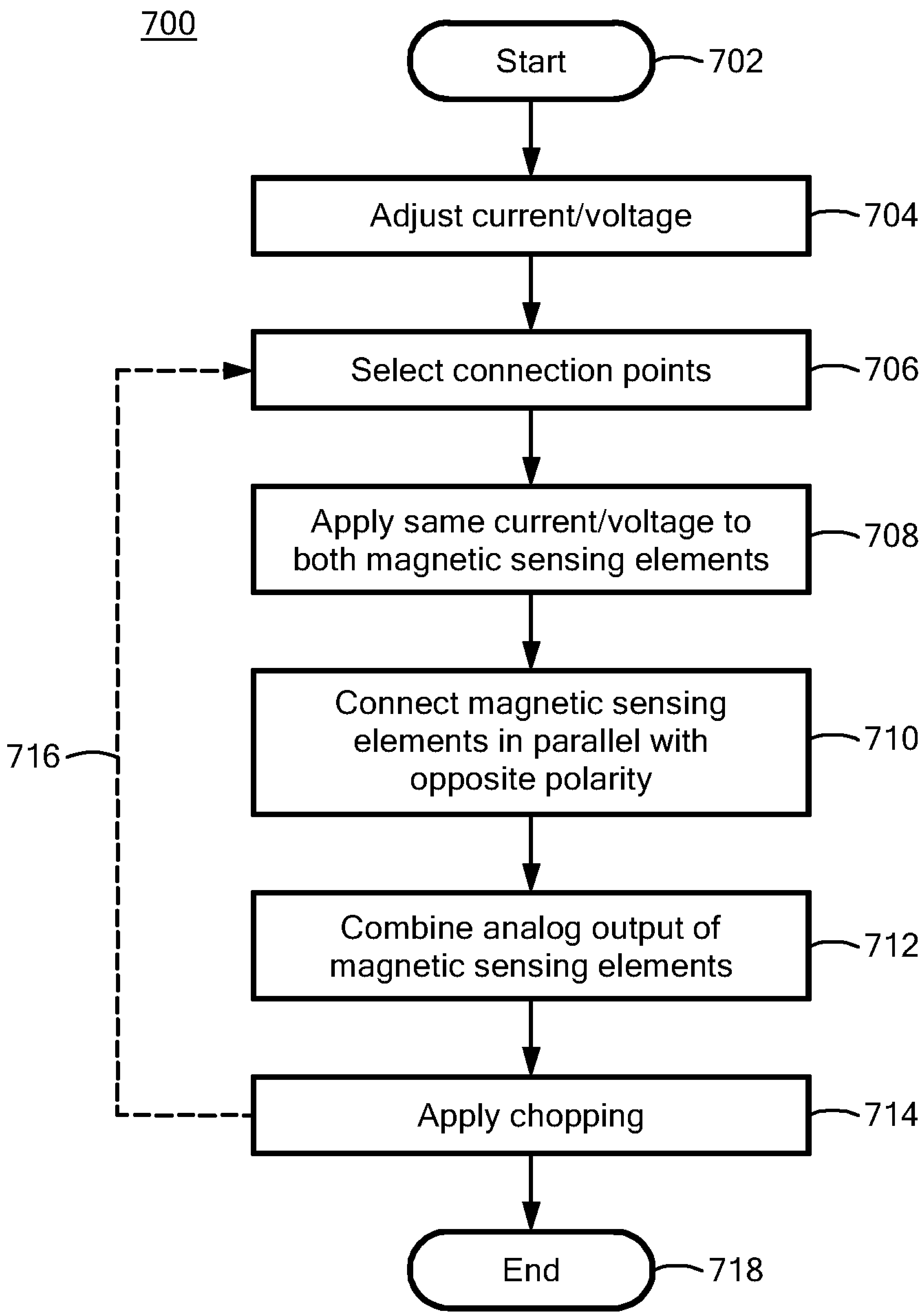

700
Start
702
Adjust current/voltage
704
Select connection points
706
Apply same current/voltage to both magnetic sensing elements
708
Connect magnetic sensing elements in parallel with opposite polarity
710
Combine analog output of magnetic sensing elements
712
Apply chopping
714
716
End
718

FIG. 7

MAGNETIC FIELD SENSORS HAVING STRAY FIELD REJECTION

CROSS REFERENCE TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

FIELD

The present disclosure relates generally to magnetic field sensors and more specifically to such sensors having stray field rejection.

BACKGROUND

Magnetic field sensors may employ one or more magnetic field sensing elements and are used in a variety of applications, including, but not limited to, a current sensor that senses a magnetic field generated by a current carried by a current-carrying conductor, a magnetic switch or proximity detector that senses proximity of a ferromagnetic or magnetic target object, a rotation detector that senses passing ferromagnetic articles, for example, gear teeth, and a magnetic field sensor that senses a magnetic field density of a magnetic field.

Various magnetic field sensors may employ a variety of types of magnetic field sensing elements, including, but not limited to, Hall effect elements, magnetoresistance elements, and magnetotransistors. Hall effect elements generate an output voltage proportional to a magnetic field. It is known that Hall effect elements can exhibit an undesirable DC (Direct Current) offset voltage. Further, some magnetic field sensors employ differential magnetic field sensing whereby spatially separated magnetic field sensing elements are used to generate a differential signal to reduce stray magnetic field effects.

SUMMARY

Described embodiments provide a magnetic field sensor having a first magnetic field sensing element and a second magnetic field sensing element disposed at a predetermined distance from the first magnetic field sensing element. The first and second magnetic field sensing elements generate first and second magnetic field signals, respectively, that are indicative of a magnetic field associated with a target. A switching module couples the first magnetic field sensing element and the second magnetic field sensing element in parallel to an amplifier by coupling a first terminal of the first magnetic field sensing element having a first polarity to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity to generate a first combined signal, and coupling a second terminal of the first magnetic field sensing element having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing element having the first polarity to generate a second combined signal. The switching module simultaneously couples the first combined signal and the second combined signal to the amplifier. The amplifier generates a magnetic field output signal indicative of a difference between the first combined signal and the second combined signal. The difference is indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled.

Aspects provide that the switching module is one or more of: a switch matrix comprising a plurality of switches, and one or more multiplexers. The switching module can provide chopping to reduce a DC offset of the first magnetic field signal and the second magnetic field signal.

Aspects provide that each of the first and second magnetic field sensing elements has four terminals, and the switching module includes a set of four switches for each terminal of the first and second magnetic field sensing elements, each set of four switches selectively coupling each terminal to one of a drive input signal having a positive polarity, a drive input signal having a negative polarity, an output signal having a positive polarity, and an output signal having a negative polarity. For the first magnetic field sensing element, a first terminal is coupled to the positive polarity drive input signal, a second terminal opposite the first terminal is coupled to the negative polarity drive input signal, a third terminal is coupled to the positive polarity output signal, and a fourth terminal is coupled to the negative polarity output signal. For the second magnetic field sensing element, a first terminal is coupled to the positive polarity drive input signal, a second terminal opposite the first terminal is coupled to the negative polarity drive input signal, a third terminal is coupled to the positive polarity output signal, and a fourth terminal is coupled to the negative polarity output signal.

Aspects provide that, to perform chopping, the switching module selectively changes which of the four terminals of the first magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, and to selectively change which of the four terminals of the second magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, wherein the selective changing reduces a DC offset of the first and second combined signals. A clock module generates a clock signal, and the switching module provides chopping based upon the clock signal.

Aspects provide that the switching module selectively provides chopping for one of: zero phases, two phases, and four phases. The switching module provides chopping for zero phases by not selectively changing which terminals of the first and second magnetic field sensing elements are coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal. The switching module provides chopping for 2 phases (2× chopping) by selectively changing between a first set of terminal connections and a second set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal. The switching module provides chopping for 4 phases (4× chopping) by selectively changing between a first set of terminal connections, a second set of terminal connections, a third set of terminal connections, and a fourth set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal.

Aspects provide that the switching module provides a determined drive signal to a selected terminal of each of the first and the second magnetic field sensing elements. The drive signal is one of a determined voltage and a determined

current. Aspects provide that a controller coupled to the switching module generates a sensor output signal indicative of the magnetic field output signal. Aspects provide that the first and second magnetic field sensing elements are one or more Hall effect elements. Aspects provide that the magnetic field output signal is proportional to a difference between the first magnetic field signal and the second magnetic field signal.

Another embodiment provides a method for sensing a magnetic field. A first magnetic field signal is generated with a first magnetic field sensing element, the first magnetic field signal indicative of a magnetic field associated with a target. A second magnetic field signal is generated with a second magnetic field sensing element spaced from the first magnetic field sensing element, the second magnetic field signal indicative of the magnetic field associated with the target. A magnetic field output signal indicative of the magnetic field is generated by coupling the first magnetic field sensing element and the second magnetic field sensing element in parallel to an amplifier by coupling a first terminal of the first magnetic field sensing element having a first polarity to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity and generating a first combined signal, and coupling a second terminal of the first magnetic field sensing element having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing element having the first polarity and generating a second combined signal. The first combined signal and the second combined signal are simultaneously coupled to the amplifier. The magnetic field output signal is generated that is indicative of a difference between the first combined signal and the second combined signal that has stray magnetic field effects cancelled.

Aspects provide chopping to reduce a DC offset of the first magnetic field signal and the second magnetic field signal. Aspects provide that each of the first and second magnetic field sensing elements has four terminals. A set of switches coupled to each terminal of the first magnetic field sensing element selectively couples a first terminal of the first magnetic field sensing element to a positive polarity drive input signal, a second terminal of the first magnetic field sensing element, opposite the first terminal, to a negative polarity drive input signal, a third terminal of the first magnetic field sensing element to a positive polarity output signal, and a fourth terminal of the first magnetic field sensing element, opposite the third terminal, to a negative polarity output signal. A set of switches coupled to each terminal of the second magnetic field sensing element selectively couples a first terminal of the second magnetic field sensing element to a positive polarity drive input signal, a second terminal of the second magnetic field sensing element, opposite the first terminal, to a negative polarity drive input signal, a third terminal of the second magnetic field sensing element to a positive polarity output signal, and a fourth terminal of the second magnetic field sensing element, opposite the third terminal, to a negative polarity output signal. Aspects selectively change which of the four terminals of the first magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, and to selectively change which of the four terminals of the second magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, wherein the selective changing reduces a DC offset of the first and second combined signals.

Aspects provide that the chopping includes performing chopping for zero phases by not selectively changing which terminals of the first and second magnetic field sensing elements are coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal. Aspects provide that the chopping includes performing chopping for 2 phases (2× chopping) by selectively changing between a first set of terminal connections and a second set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal. Aspects provide that the chopping includes performing chopping for 4 phases (4× chopping) by selectively changing between a first set of terminal connections, a second set of terminal connections, a third set of terminal connections, and a fourth set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal.

Aspects provide a determined drive signal to a selected terminal of each of the first and the second magnetic field sensing elements. The drive signal is one of a determined voltage and a determined current. Aspects generate a sensor output signal indicative of the magnetic field output signal. Aspects provide that the first and second magnetic field sensing elements each comprise one or more Hall effect elements.

Another embodiment provides a magnetic field sensor having a first magnetic field sensing element to generate a first magnetic field signal indicative of a magnetic field associated with a target, and a second magnetic field sensing element, disposed at a predetermined distance from the first magnetic field sensing element, to generate a second magnetic field signal indicative of the magnetic field associated with the target. The first magnetic field sensing element and the second magnetic field sensing element are coupled in parallel to an amplifier. A first terminal of the first magnetic field sensing element having a first polarity is coupled to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity to generate a first combined signal. A second terminal of the first magnetic field sensing element having a polarity opposite the first polarity is coupled to a second terminal of the second magnetic field sensing element having the first polarity to generate a second combined signal. The first combined signal and the second combined signal are provided to the amplifier, which generates a magnetic field output signal indicative of a difference between the first combined signal and the second combined signal. The difference is indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled.

Another embodiment provides a magnetic field sensor having first magnetic field sensing means to generate a first magnetic field signal indicative of a magnetic field associated with a target, and second magnetic field sensing means, disposed at a predetermined distance from the first magnetic field sensing means, to generate a second magnetic field signal indicative of the magnetic field associated with the target. Switching means couple the first magnetic field sensing means and the second magnetic field sensing means in parallel to amplification means. The switching means couples a first terminal of the first magnetic field sensing means having a first polarity to a first terminal of the second magnetic field sensing means having a polarity opposite the first polarity to generate a first combined signal. The switching means couples a second terminal of the first magnetic field sensing means having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing means having the first polarity to generate a second combined signal. The switching means simultaneously couples the first combined signal and the second combined signal to the amplification means. The amplification means generates a magnetic field output signal indicative of a difference between the first combined signal and the second combined signal. The difference is indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled.

Another embodiment provides a magnetic field sensor having first magnetic field sensing means to generate a first magnetic field signal indicative of a magnetic field associated with a target and second magnetic field sensing means, disposed at a predetermined distance from the first magnetic field sensing means, to generate a second magnetic field signal indicative of the magnetic field associated with the target. The first magnetic field sensing means and the second magnetic field sensing means are coupled in parallel to amplification means. A first terminal of the first magnetic field sensing means having a first polarity is coupled to a first terminal of the second magnetic field sensing means having a polarity opposite the first polarity to generate a first combined signal. A second terminal of the first magnetic field sensing means having a polarity opposite the first polarity is coupled to a second terminal of the second magnetic field sensing means having the first polarity to generate a second combined signal. The first combined signal and the second combined signal are provided to the amplification means. The amplification means generates a magnetic field output signal indicative of a difference between the first combined signal and the second combined signal. The difference is indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled.

BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects, features, and advantages will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which like reference numerals identify similar or identical elements. Reference numerals that are introduced in the specification in association with a drawing figure may be repeated in one or more subsequent figures without additional description in the specification in order to provide context for other features.

FIG. **1** shows a block diagram of a magnetic field sensor in accordance with described embodiments;

FIG. **2** shows an arrangement of Hall effect sensing elements of a magnetic field sensor in accordance with the prior art;

FIG. **3** shows an arrangement of Hall effect sensing elements of a magnetic field sensor in accordance with described embodiments;

FIG. **4** shows an illustrative schematic of a chopping circuit in accordance with described embodiments;

FIGS. **5**A, **5**B, **5**C, and **5**D show output connections of a magnetic field sensor employing a chopping circuit in accordance with described embodiments;

FIG. **6** shows an illustrative schematic of a magnetic field sensor circuit in accordance with described embodiments; and

FIG. **7** shows a flow diagram of a technique of operating a magnetic field sensor in accordance with described embodiments.

DETAILED DESCRIPTION

In accordance with described embodiments, a magnetic field sensor is provided having a first magnetic field sensing element and a second magnetic field sensing element disposed at a predetermined distance from the first magnetic field sensing element. The first and second magnetic field sensing elements generate first and second magnetic field signals, respectively, that are indicative of a magnetic field associated with a target. A switching module couples the first magnetic field sensing element and the second magnetic field sensing element in parallel to an amplifier by coupling a first terminal of the first magnetic field sensing element having a first polarity to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity to generate a first combined signal, and coupling a second terminal of the first magnetic field sensing element having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing element having the first polarity to generate a second combined signal. The switching module simultaneously couples the first combined signal and the second combined signal to the amplifier. The amplifier generates a magnetic field output signal indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled.

By way of introduction, as used herein, the term "magnetic field sensing element" describes a variety of types of electronic elements that sense a magnetic field. The magnetic field sensing elements can be, but are not limited to, Hall effect elements, magnetoresistance elements, or magnetotransistors. There are different types of Hall effect elements, for example, planar Hall elements, vertical Hall elements, and circular Hall elements. There are different types of magnetoresistance elements, for example, anisotropic magnetoresistance (AMR) elements, giant magnetoresistance (GMR) elements, tunneling magnetoresistance (TMR) elements, Indium antimonide (InSb) elements, and magnetic tunnel junction (MTJ) elements. Most, but not all, types of magnetoresistance elements tend to have axes of maximum sensitivity parallel to a substrate that supports the magnetic field sensing element and most, but not all, types of Hall elements tend to have axes of sensitivity perpendicular to a substrate that supports the magnetic field sensing element.

As used herein, the term "magnetic field sensor" describes a circuit that includes one or more magnetic field sensing elements. Magnetic field sensors are used in a variety of applications, including, but not limited to, a current sensor that senses a magnetic field generated by a current carried by a current-carrying conductor, a magnetic switch or proximity detector that senses the proximity of a ferromagnetic or magnetic object, a rotation detector that senses passing ferromagnetic articles, for example, gear teeth, and a magnetic field sensor that senses a magnetic field density of a magnetic field. In general, the circuits and techniques described herein apply to any magnetic field sensor capable of detecting a magnetic field.

FIG. **1** shows a block diagram of a magnetic field sensor, shown as magnetic field sensor **100**. In described embodiments, magnetic field sensor **100** may be a magnetic angle and linear position sensing integrated circuit for consumer, industrial, and automotive applications. Magnetic field sensor **100** may employ various types of magnetic field sensing elements **110**, **112** to sense a magnetic field associated with a target **160**. In some embodiments, target **160** may be a magnetic element. In other embodiments, target **160** may be a ferromagnetic element that affects a magnetic field when positioned in proximity to a magnet **170** (e.g., a back-biased configuration). In some embodiments, magnetic field sensor **100** may be provided as an integrated circuit.

As shown in FIG. **1**, magnetic field sensor **100** may include analog front end (AFE) **102** and digital system **104**. Power system **106** may receive one or more input voltages (shown as voltage signal VCC in FIG. **1**) and a ground or common signal (shown as GND signal in FIG. **1**). Power system **106** may provide power signals (e.g., one or more voltages) to AFE **102** and digital system **104**, as well as to one or more other sensors **108**. In some embodiments, other sensors **108** may include one or more additional sensors to sense conditions of magnetic field sensor **100** and/or the environment in which magnetic field sensor **100** is deployed, for example one or more temperature sensors for use to compensate sensitivity and/or offset of magnetic field sensor **100** over temperature.

In some embodiments, AFE **102** may include a plurality of magnetic field sensing elements, shown as Hall effect elements **110** and **112**. It will be appreciated that in various embodiments, other types of magnetic field sensing elements may be used and also that other numbers of magnetic field sensing elements may be used.

Hall effect elements **110** and **112** may be coupled to switching and amplification circuit **114**, which is described in greater detail in regard to FIG. **4**. As shown, Hall effect elements **110** and **112** may provide respective magnetic field signals **138***a* and **138***b* to switching and amplification circuit **114**. In some embodiments, one or more amplifiers may amplify the signals output from Hall effect elements **110** and **112**.

Switching and amplification circuit **114** may provide combined analog output signal **140** to analog-to-digital converter (ADC) **116**, which converts combined analog output signal **140** into digital output signal **142**, which in turn is provided to digital system **104**. As will be described, digital system **104** may process the received digital signal **142** and, in response, generate one or more output signals from magnetic field sensor **100**. For example, in some embodiments, magnetic field sensor **100** may be in communication with an engine control unit (ECU) of a vehicle, or other control unit in a system in which magnetic field sensor **100** is deployed, via one or more signals received by or transmitted from magnetic field sensor **100** (e.g., SENT/PWM signal shown in FIG. **1**).

In some embodiments, elements **110** and **112** may be disposed proximate to one another at a predetermined distance (e.g., on the order of millimeters apart). In one embodiment, the elements may be on the order of 2-3 mm apart in order to sense a difference in magnetic field gradients between the elements and may generally be referred to herein in directional terms, such as "left" and "right" elements. According to the disclosure, output signals **138***a*, **138***b* from respective spatially separated magnetic field sensing elements **110**, **112** can be combined (e.g., subtracted) by switching and amplification circuit **114** such that any effects from stray magnetic fields experienced by both sensing elements (i.e., common to both elements) tend to cancel in the resulting differential magnetic field signal **140**, whereas the field that is desired to be detected can be readily detectable from the resulting differential magnetic field signal.

In some embodiments, each magnetic field sensing element **110**, **112** has multiple terminals, or contacts. For example, in embodiments, elements **110**, **112** are Hall effect elements or plates, each having four terminals, two of which are coupled to a bias or drive source (i.e., current or voltage source) and two of which provide a differential element output signal. It will be appreciated that, in embodiments, described elements **110**, **112** may each include more than one such element configured to permit magnetic field sensing in three dimensions, as may be achieved using planar and vertical Hall elements. Thus, elements **110**, **112** can each include one or more than one magnetic field sensing element of various types, which types can be the same or different.

As will be described in greater detail in regard to FIGS. **3**, **4** and **5**, switching and amplification circuit **114** is configured to selectively couple elements **110** and **112** and generate combined analog output signal **140**. In such embodiments, switching and amplification circuit **114** couples drive signals to selected terminals of each element **110** and **112**, and couples other selected terminals of elements **110** and **112** to each other and to an amplifier. As will be described, switching and amplification circuit **114** may be configured to couple analog output signals from each element such that the output signal from one of the elements has an inverted polarity with respect to the output signal from the other element. The two analog output signals may be directly combined to form a combined analog output signal **140** that has cancelled the effects from stray magnetic signals (e.g., common mode effects). As will be described, this may allow use of only a single amplifier to generate the combined analog output signal, rather than processing the output of each element separately. Additionally, by directly combining the output signals of the elements in the analog domain, more complex circuitry and/or processing algorithms can be avoided.

Additionally, as will be described in greater detail in regard to FIGS. **4** and **5**, in some embodiments, to reduce DC offset of the Hall effect elements, "chopping" or "current spinning" may be employed. Chopping refers to driving a Hall effect element in two or more different directions by changing which sensing element terminals are coupled to power and ground connections and receiving output signals at different terminals as the Hall effect element is differently driven. In such embodiments, switching and amplification circuit **114** may also receive clock signal(s) from clock module **124** and/or control signal(s) from controller **126**. In this way, selected drive and output signal contact pairs are interchanged during each phase of the chopping and offset voltages tend to cancel. Thus, in described embodiments, switching and amplification circuit **114** may achieve both DC offset reduction and stray effect cancellation for magnetic field sensor **100**.

As shown in FIG. **1**, digital system **104** may include filtering module **118** that is coupled to receive digital signal **142** from ADC **116**. In described embodiments, filtering module **118** may be a low pass filter having various forms including, but not limited to, a cascaded integrator-comb (CIC) decimation filter or a switched capacitor filter. Digital system **104** may also include clock module **124**, which is coupled to, and provides one or more clock signals to, controller **126**. In described embodiments, controller **126** is coupled to receive filtered magnetic field output signal **144** from filter module **118** and, in response, is configured to generate a sensor output signal as may be transmitted by SENT/PWM transmitter **130** of communication interface **134**. For example, controller **126** may provide signal(s) to SENT/PWM transmitter **130** to generate an output signal of magnetic field sensor **100** to be transmitted to an external device coupled to magnetic field sensor **100**, such as an ECU (not shown). The SENT/PWM output signal is generally indicative of an output of the magnetic field sensing elements **110** and **112**. For example, the SENT/PWM output signal may indicate one or more of a position of the target, a speed of motion of the target, a direction of motion of the target, and an angle of the target.

As shown in FIG. **1**, SENT/PWM signal may be a bidirectional communication signal to send and receive data to/from devices external to magnetic field sensor **100**, such as an ECU. Serial receiver **136** may receive signals and provide received data to controller **126**. In some embodiments, serial receiver **136** may decode Manchester encoded serial data and provide a received signal to controller **126**. Controller **126** may adjust operation of magnetic field sensor **100** in response to a received signal, or may transmit a response via SENT/PWM transmitter **130**. Controller **126** may also be coupled to memory **122**, which may store data associated with operation of magnetic field sensor **100**, for example past values of the SENT/PWM output signal, past data output from elements **110** and **112** (e.g., past values of filtered magnetic field output signal **144**), data received (e.g., received from an ECU), variable settings for operation of magnetic field sensor **100**, and so forth. Further, in some embodiments, controller **126** might be configured to adjust biasing or trimming of elements **110** and **112**.

It will be appreciated that while communication interface **134** is described as transmitting and receiving a SENT and/or PWM formatted signal, other signal formats are possible for communicating sensor information including, but not limited to, I^2C, SPI (serial peripheral interface), and A/B/I format.

FIG. **2** shows a block diagram of a conventional magnetic field sensing element arrangement **200**. As shown, in a conventional system, two magnetic field sensing elements (e.g., Hall effect elements) **202** and **204** might be employed to detect a magnetic field. As shown, each Hall effect sensing element **202** and **204** might have four contacts, or terminals (1, 2, 3, 4). Two contacts from Hall effect sensing element **202** (shown as signals **206** and **208**) are coupled to amplifier **210**, and two contacts from Hall effect sensing element **204** (shown as signals **214** and **216**) are coupled to amplifier **218**. As shown, one input for each of amplifiers **210** and **218** might generally be a positive input, and one input for each of amplifiers **210** and **218** might generally be a negative input. Amplifiers **210** and **218** generate output signals **212** and **220**, respectively. Output signals **212** and **220** are then summed to generate magnetic field output signal **222**. Amplifiers **210** and **218** amplify the outputs **206**, **208**, **214** and **216** of the Hall effect sensing elements **202** and **204**.

Thus, as shown in FIG. **2**, a conventional system includes two dedicated amplifiers (**210**, **218**) that are coupled to Hall effect sensing elements **202** and **204**, and then the difference is taken at the output of the amplifiers **210**, **218** to generate magnetic field signal **222**. Such a system requires two amplifiers **210** and **218** with their respective power and physical space requirements and preferably requires matching of the amplifier characteristics.

FIG. **3** shows a block diagram of a magnetic field sensing element arrangement **300** in accordance with described embodiments. As will be described, some embodiments provide an arrangement for magnetic field sensing elements that determines an analog difference of magnetic fields sensed by the magnetic field sensing elements, which achieves improved stray field immunity, particularly for high frequency stray fields. Some embodiments may also provide a signal chopping scheme to reduce or eliminate DC offset.

As shown in FIG. **3**, a described embodiment may include two magnetic field sensing elements (e.g., Hall effect sensing elements) **302** and **304** to detect a magnetic field. As shown, each Hall effect sensing element **302** and **304** may have four contacts (1, 2, 3, 4). One contact from Hall effect sensing element **302** (shown as signal **306**) is coupled to an opposite polarity contact from Hall effect sensing element **304** (shown as signal **310**) to generate combined signal **311**. Another contact from Hall effect sensing element **302** (shown as signal **308**, having the opposite polarity of signal **306**) is coupled to an opposite polarity contact from Hall effect sensing element **304** (shown as signal **312**) to generate combined signal **313**. Combined signals **311** and **313** are provided to inputs of amplifier **316** to generate a difference signal **314**. The Hall elements are concurrently or simultaneously driven with a current in the same direction through both elements, and with a current having the same phase. However, output signals of opposite polarity are coupled to each other. With this arrangement, the field effects common to both elements (such as stray fields) cancel, thereby resulting in an output that is stray field immune. A differential field (the field desired to be detected) has the same polarity for each of the two Hall effect elements, and thus the output signal resulting from the configuration **300** will be one-half of the drive voltage level.

Thus, as shown in FIG. **3**, described embodiments include only one amplifier **316** coupled to Hall effect sensing elements **302** and **304** to generate difference signal **314** in the analog domain by connecting the magnetic field sensor output signals in a particular manner, and then processing the combined signals **311** and **313** through a single FEAMP (**316**) to generate difference signal **314**. Advantages of such embodiments over conventional systems include a capability of rejecting high frequency stray field immunity without needing to employ complex ADC and/or DSP, lower cost, lower power consumption, and smaller physical size due to only employing one amplifier, and having the only source of signal error be due to Hall effect sensing element sensitivity mismatch, which can be compensated.

Referring also to FIG. **4**, magnetic field sensing element arrangement **400** including elements **302**, **304** (FIG. **3**) is shown to be coupled to respective switch networks or arrays **402**, **404**, respectively. Switch arrays **402**, **404** can form part of switching and amplification circuit **114** (FIG. **1**) and, in general, can be coupled between sensing elements **302**, **304** and an amplifier (e.g., amplifier **316** in FIG. **3**) and controlled in order to selectively couple sensing element terminals to inputs of the amplifier. First Hall effect sensing element **302** and second Hall effect sensing element **304** may generally be referred to as "left" and "right" elements, as shown in FIG. **4**, although this is meant to easily differentiate between the two different elements and does not necessarily imply a directionality of the elements.

Table 1 below illustrates control of switches within the switch arrays **402**, **404**. Signal hp**1**_sw<15:0> may generally be a digital input signal to control switch array **402** for "left" element **302**. Signal hpr_sw<15:0> may generally be a digital input signal to control switch array **404** for "right" element **304**. Each element **302** and **304** may have a positive and a negative analog output signal, which is selected by the respective switch arrays **402** and **404**, from the respective "left" and "right" element terminals "HL**1**"-"HL**4**" and "HR**1**"-"HR**4**". Signals hp**1**_sw and hpr_sw may generally be provided to switch arrays **402** and **404** by digital controller **126** of FIG. **1**. As shown in Table 1, "V+" may represent the positive output signal of a given element, "V−" may represent the negative output signal of a given element, and "I+" may represent the positive bias input (current or voltage) of a given element, and "I−" may represent the negative bias input (current or voltage) of a given element. In a desirable embodiment, both elements **302**, **304** have effectively the same or substantially similar sensitivity to magnetic fields.

Table 1 contains rows corresponding to different operational phases. Such phases refer to chopping phases in embodiments implementing chopping. Thus, in embodiments that do not implement chopping, only a single phase may be used. Table 1 illustrates a 4 phase chopping scheme and the Hall plate connections are illustrated in FIGS. **5**A-**5**D for respective phases **0**-**3**.

TABLE 1

		Left plate switch <15:0>				Right plate switch <15:0>			
Phase (FIG.)	Output	<15:12> HL1	<11:8> HL2	<7:4> HL3	<3:0> HL4	<15:12> HR1	<11:8> HR2	<7:4> HR3	<3:0> HR4
0	L-R	1000	0100	0010	0001	1000	0001	0010	0100
FIG. 5A		I+	V+	I−	V−	I+	V−	I−	V+
1	-(L-R)	0001	1000	0100	0010	0100	1000	0001	0010
FIG. 5B		V−	I+	V+	I−	V+	I+	V−	I−
2	L-R	0010	0001	1000	0100	0010	0100	1000	0001
FIG. 5C		I−	V−	I+	V+	I−	V+	I+	V−
3	-(L-R)	0100	0010	0001	1000	0001	0010	0100	1000
FIG. 5D		V+	I−	V−	I+	V−	I−	V+	I+

FIGS. **5**A-**5**D show output connections of a magnetic field sensor employing a chopping circuit in accordance with described embodiments, for example as shown in FIG. **4** and Table 1. For example, FIG. **5**A shows the connection of "left" and "right" Hall elements **302** and **304** for phase **0**, as shown in Table 1. As shown in Table 1, during phase **0**, terminal HL**2** of "left" Hall element **302** is coupled to "V+", and terminal HL**4** of "left" Hall element **302** is coupled to "V−", while terminal HR**2** of "right" Hall element **304** is coupled to "V−", and terminal HR**4** of "right" Hall element **304** is coupled to "V+". Each Hall element is driven by an input current applied from terminal **1** (e.g., HL**1** and HR**1** are "I+") to terminal **3** (e.g., HL**3** and HR**3** are "I−"). Thus, as shown, the two Hall elements are concurrently or simultaneously driven with a current in the same direction through both elements, and with a current having the same phase. However, output signals of opposite polarity are coupled to each other, resulting in differential signals that subtract, thus cancelling the effect of stray fields and resulting in an output that is stray field immune. Thus, as shown in FIG. **5**A, terminal HL**2** is coupled to terminal HR**4** to generate HOUTP (e.g., the positive differential output signal of the magnetic field sensor), and terminal HL**4** is coupled to terminal HR**2** to generate HOUTN (e.g., the negative differential output signal of the magnetic field sensor), resulting in an output voltage of the magnetic field sensor that is equal to the left sensing element signal minus the right sensing element signal (e.g., sig_L-sig_R). The subtraction of the differential signals occurs by reversing the polarity of one plate relative to the other.

FIG. **5**B shows the connection of "left" and "right" Hall elements **302** and **304** for phase **1**, as shown in Table 1. As shown in Table 1, during phase **1**, terminal HL**3** of "left" Hall element **302** is coupled to "V+", and terminal HL**1** of "left" Hall element **302** is coupled to "V−", while terminal HR**3** of "right" Hall element **304** is coupled to "V−", and terminal HR**1** of "right" Hall element **304** is coupled to "V+". Each Hall element is driven by an input current applied from terminal **2** (e.g., HL**2** and HR**2** are "I+") to terminal **4** (e.g., HL**4** and HR**4** are "I−"). Thus, as shown, the two Hall elements are concurrently or simultaneously driven with a current in the same direction through both elements, and with a current having the same phase. However, signals of opposite polarity are coupled to each other, resulting in differential signals that subtract, thus cancelling stray field signals and resulting in an output that is stray field immune. Thus, as shown in FIG. **5**B, terminal HL**3** is coupled to terminal HR**1** to generate HOUTP (e.g., the positive differential output signal of the magnetic field sensor), and terminal HL**1** is coupled to terminal HR**3** to generate HOUTN (e.g., the negative differential output signal of the magnetic field sensor), resulting in an output voltage of the magnetic field sensor that is equal to the left sensing element signal less the right sensing element signal (e.g., $-(sig_L$-$sig_R))$. The subtraction of the differential signals occurs by reversing the polarity of one plate relative to the other.

FIG. **5**C shows the connection of "left" and "right" Hall elements **302** and **304** for phase **2**, as shown in Table 1. As shown in Table 1, during phase **2**, terminal HL**4** of "left" Hall element **302** is coupled to "V+", and terminal HL**2** of "left" Hall element **302** is coupled to "V−", while terminal HR**4** of "right" Hall element **304** is coupled to "V−", and terminal HR**2** of "right" Hall element **304** is coupled to "V+". Each Hall element is driven by an input current applied from terminal **3** (e.g., HL**3** and HR**3** are "I+") to terminal **1** (e.g., HL**1** and HR**1** are "I−"). Thus, as shown, the two Hall elements are concurrently or simultaneously driven with a current in the same direction through both elements, and with a current having the same phase. However, signals of opposite polarity are coupled to each other, resulting in differential signals that subtract, thus cancelling stray field signals and resulting in an output that is stray field immune. Thus, as shown in FIG. **5**C, terminal HL**4** is coupled to terminal HR**2** to generate HOUTP (e.g., the positive differential output signal of the magnetic field sensor), and terminal HL**2** is coupled to terminal HR**4** to generate HOUTN (e.g., the negative differential output signal of the magnetic field sensor), resulting in an output voltage of the magnetic field sensor that is equal to the left sensing element signal less the right sensing element signal (e.g., $sig_L - sig_R$). The subtraction of the differential signals occurs by reversing the polarity of one plate relative to the other.

FIG. **5**D shows the connection of "left" and "right" Hall elements **302** and **304** for phase **3**, as shown in Table 1. As shown in Table 1, during phase **3**, terminal HL**1** of "left" Hall element **302** is coupled to "V+", and terminal HL**3** of "left" Hall element **302** is coupled to "V−", while terminal HR**1** of "right" Hall element **304** is coupled to "V−", and terminal HR**3** of "right" Hall element **304** is coupled to "V+". Each Hall element is driven by an input current applied from terminal **4** (e.g., HL**4** and HR**4** are "F") to terminal **2** (e.g., HL**2** and HR**2** are "I−"). Thus, as shown, the two Hall elements are concurrently or simultaneously driven with a current in the same direction through both elements, and with a current having the same phase. However, signals of opposite polarity are coupled to each other, resulting in differential signals that subtract, thus cancelling stray field signals and resulting in an output that is stray field immune. Thus, as shown in FIG. **5**D, terminal HL**1** is coupled to terminal HR**3** to generate HOUTP (e.g., the positive differential output signal of the magnetic field sensor), and terminal HL**3** is coupled to terminal HR**1** to generate HOUTN (e.g., the negative differential output signal of the magnetic field sensor), resulting in an output voltage of the magnetic field sensor that is equal to the left sensing element signal less the right sensing element signal (e.g., $-(sig_L-sig_R)$). The subtraction of the differential signals occurs by reversing the polarity of one plate relative to the other.

As shown in FIGS. **5**A-**5**D, in embodiments where DC offset is an important consideration, chopping may be employed to "rotate" through **2** or **4** of the phases shown in Table 1 to eliminate the offset signal (e.g., off_L-off_R). Note that in each chopping phase shown in Table 1, the negative voltage output of one of the Hall elements is coupled to the positive of voltage output of the other Hall element, and vise-versa, thereby maintaining the stray field immunity benefits of the Hall plate configuration during chopping.

FIG. **6** shows a block diagram of a signal processing path of a magnetic field sensor such as shown in FIG. **1**. As shown in FIG. **6**, magnetic field sensor system **600** includes two or more spaced magnetic field sensing elements **602** and **604**, each spaced from the other by a predetermined distance, for sensing a magnetic field affected by a target (not shown in FIG. **6**) and generating respective magnetic field signals **606** and **608**. A modulator, as may take the form of a switching module **610**, is coupled to receive the first and second magnetic field signals **606** and **608** and is configured to generate a combined signal **612**. Amplifier **614** is coupled to receive the combined signal **612** and generate amplified signal **616**. Analog-to-digital converter (ADC) **618** may be provided to convert the amplified signal **616** into a digital signal **620**.

Filter **622** is coupled to receive the digital signal **620** and generate an output signal **624**. In some embodiments, filter **622** is a low pass filter having a cutoff frequency less than or equal to a rate of the clock signal (CLK) and a zero at the frequency of the clock signal (CLK). Various forms and types of low pass filters are possible including, but not limited to a cascaded integrator-comb (CIC) decimation filter or a switched capacitor filter. The magnetic field sensor **600** may be provided in the form of an integrated circuit in some embodiments.

FIG. **7** shows an illustrative method **700** for sensing a magnetic field, for example using magnetic field sensor **100**. At block **702**, process **700** begins. At block **704**, a bias current and/or bias voltage applied to each of the magnetic field sensing elements (e.g., **110** and **112** of FIG. **1**) may optionally be adjusted, for example to adjust a DC offset of the magnetic field sensing elements. At block **706**, when chopping is being employed, connection points may be selected for the magnetic field sensing elements, for example as described in regard to Table 1 and FIGS. **4** and **5**A-**5**D. At block **708**, the selected currents and/or voltages are applied to both magnetic field sensing elements. At block **710**, the switch arrays connect the magnetic field sensing elements in parallel with opposite polarity to the amplifier as described in connection with FIG. **3**. At block **712**, the analog magnetic field sensing element output signals are combined and applied to the amplifier, which amplifies the combined analog signals and generates an output signal in which high frequency stray fields are rejected. At block **714**, chopping is optionally applied, for example by returning process **700** to block **706** to select new connection points for the magnetic field sensing elements, for example as described in regard to Table 1 and FIGS. **4** and **5**A-**5**D. At block **718**, process **700** is complete. Alternatively, process **700** may continue to run, for example as long as system **100** is powered.

Thus, as described herein, embodiments provide a magnetic field sensor having a first magnetic field sensing element and a second magnetic field sensing element disposed at a predetermined distance from the first magnetic field sensing element. The first and second magnetic field sensing elements generate first and second magnetic field signals, respectively, that are indicative of a magnetic field associated with a target. A switching module couples the first magnetic field sensing element and the second magnetic field sensing element in parallel to an amplifier by coupling a first terminal of the first magnetic field sensing element having a first polarity to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity to generate a first combined signal, and coupling a second terminal of the first magnetic field sensing element having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing element having the first polarity to generate a second combined signal. The switching module simultaneously couples the first combined signal and the second combined signal to the amplifier. The amplifier generates a magnetic field output signal indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled.

Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the claimed subject matter. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments necessarily mutually exclusive of other embodiments. The same applies to the term "implementation."

Some embodiments might be implemented in the form of methods and apparatuses for practicing those methods. Further, as would be apparent to one skilled in the art, various functions of circuit elements may be implemented as a software program. Described embodiments might be implemented in the form of program code embodied in tangible media, such as magnetic media, optical media, solid state memory, hard drives, or any other machine-readable storage medium, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the method implemented by the program code. When implemented on one or more processors, including for example, one or more digital signal processors (DSPs), central processing units (CPUs), graphics processing units (GPUs), microcontrollers, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or general purpose computers, the program code combines with the processor(s) to provide a unique device that operates analogously to specific logic circuits.

It should be understood that the steps of the illustrative methods set forth herein are not necessarily required to be performed in the order described. Likewise, additional steps may be included in such methods, and certain steps may be omitted or combined, in methods consistent with various embodiments.

It will be further understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated in order to explain the nature of the described embodiments might be made by those skilled in the art without departing from the scope of the following claims.

What is claimed is:

1. A magnetic field sensor comprising:

a first magnetic field sensing element configured to generate a first magnetic field signal indicative of a magnetic field associated with a target;

a second magnetic field sensing element, disposed at a predetermined distance from the first magnetic field sensing element, configured to generate a second magnetic field signal indicative of the magnetic field associated with the target, wherein each of the first and second magnetic field sensing elements has four terminals; and

a switching module configured to couple the first magnetic field sensing element and the second magnetic field sensing element in parallel to an amplifier, the switching module comprising one or more of: a switch matrix comprising a plurality of switches, and one or more multiplexers and configured to:

couple a first terminal of the first magnetic field sensing element having a first polarity to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity to generate a first combined signal;

couple a second terminal of the first magnetic field sensing element having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing element having the first polarity to generate a second combined signal; and

simultaneously couple the first combined signal and the second combined signal to the amplifier, the amplifier configured to generate a magnetic field output signal indicative of a difference between the first combined signal and the second combined signal, wherein the difference is indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled;

wherein the switching module comprises:

a set of four switches for each terminal of the first and second magnetic field sensing elements, each set of four switches configured to selectively couple each terminal to one of a drive input signal having a positive polarity, a drive input signal having a negative polarity, an output signal having a positive polarity, and an output signal having a negative polarity,

wherein, for the first magnetic field sensing element, the first terminal is coupled to the positive polarity drive input signal, the second terminal opposite the first terminal is coupled to the negative polarity drive input signal, a third terminal is coupled to the positive polarity output signal, and a fourth terminal is coupled to the negative polarity output signal, and

wherein, for the second magnetic field sensing element, the first terminal is coupled to the positive polarity drive input signal, the second terminal opposite the first terminal is coupled to the negative polarity drive input signal, a third terminal is coupled to the positive polarity output signal, and a fourth terminal is coupled to the negative polarity output signal.

2. The magnetic field sensor of claim **1**, wherein the switching module is further configured to provide chopping to reduce a DC (Direct Current) offset of the first magnetic field signal and the second magnetic field signal.

3. The magnetic field sensor of claim **2**, wherein, to provide chopping, the switching module is configured to selectively change which of the four terminals of the first magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, and to selectively change which of the four terminals of the second magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, wherein the selective changing reduces a DC (Direct Current) offset of the first and second combined signals.

4. The magnetic field sensor of claim **3**, further comprising a clock module configured to generate a clock signal, and wherein the switching module is configured to provide chopping based upon the clock signal.

5. The magnetic field sensor of claim **3**, wherein the switching module is configured to selectively provide chopping for one of:

zero phases by not selectively changing which terminals of the first and second magnetic field sensing elements are coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal;

2 phases (2× chopping) by selectively changing between a first set of terminal connections and a second set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal; and

4 phases (4× chopping) by selectively changing between a first set of terminal connections, a second set of terminal connections, a third set of terminal connections, and a fourth set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal.

6. The magnetic field sensor of claim **1**, wherein the switching module is further configured to provide a determined drive signal to a selected terminal of each of the first and the second magnetic field sensing elements.

7. The magnetic field sensor of claim **6**, wherein the drive signal is one of a determined voltage and a determined current.

8. The magnetic field sensor of claim **1**, further comprising a controller coupled to the switching module and configured to generate a sensor output signal indicative of the magnetic field output signal.

9. The magnetic field sensor of claim **1**, wherein the first and second magnetic field sensing elements comprise one or more Hall effect elements.

10. The magnetic field sensor of claim 1, wherein the magnetic field output signal is proportional to a difference between the first magnetic field signal and the second magnetic field signal.

11. A method for sensing a magnetic field, the method comprising:

generating a first magnetic field signal with a first magnetic field sensing element, the first magnetic field signal indicative of a magnetic field associated with a target;

generating a second magnetic field signal with a second magnetic field sensing element spaced from the first magnetic field sensing element, the second magnetic field signal indicative of the magnetic field associated with the target, wherein each of the first and second magnetic field sensing elements has four terminals;

generating a magnetic field output signal indicative of the magnetic field by coupling the first magnetic field sensing element and the second magnetic field sensing element in parallel to an amplifier, the coupling comprising:

coupling a first terminal of the first magnetic field sensing element having a first polarity to a first terminal of the second magnetic field sensing element having a polarity opposite the first polarity and generating a first combined signal;

coupling a second terminal of the first magnetic field sensing element having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing element having the first polarity and generating a second combined signal;

simultaneously coupling the first combined signal and the second combined signal to the amplifier; and

generating the magnetic field output signal, wherein the magnetic field output signal is indicative of a difference between the first combined signal and the second combined signal that has stray magnetic field effects cancelled

selectively coupling, by a set of switches coupled to each terminal of the first magnetic field sensing element, the first terminal of the first magnetic field sensing element to a positive polarity drive input signal, the second terminal of the first magnetic field sensing element, opposite the first terminal, to a negative polarity drive input signal, a third terminal of the first magnetic field sensing element to a positive polarity output signal, and a fourth terminal of the first magnetic field sensing element, opposite the third terminal, to a negative polarity output signal; and

selectively coupling, by a set of switches coupled to each terminal of the second magnetic field sensing element, the first terminal of the second magnetic field sensing element to a positive polarity drive input signal, the second terminal of the second magnetic field sensing element, opposite the first terminal, to a negative polarity output signal, a third terminal of the second magnetic field sensing element to a positive polarity output signal, and a fourth terminal of the second magnetic field sensing element, opposite the third terminal, to a negative polarity output signal.

12. The method of claim 11, further comprising:

providing chopping to reduce a DC (Direct Current) offset of the first magnetic field signal and the second magnetic field signal.

13. The method of claim 12, further comprising:

selectively changing which of the four terminals of the first magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, and to selectively change which of the four terminals of the second magnetic field sensing element is coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal, wherein the selective changing reduces a DC (Direct Current) offset of the first and second combined signals.

14. The method of claim 13, wherein the chopping comprises one of:

performing chopping for zero phases by not selectively changing which terminals of the first and second magnetic field sensing elements are coupled to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal;

performing chopping for 2 phases (2× chopping) by selectively changing between a first set of terminal connections and a second set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal; and

performing chopping for 4 phases (4× chopping) by selectively changing between a first set of terminal connections, a second set of terminal connections, a third set of terminal connections, and a fourth set of terminal connections to the positive polarity drive input signal, the negative polarity drive input signal, the positive polarity output signal, and the negative polarity output signal.

15. The method of claim 11, further comprising:

providing a determined drive signal to a selected terminal of each of the first and the second magnetic field sensing elements.

16. The method of claim 15, wherein the drive signal is one of a determined voltage and a determined current.

17. The method of claim 11, further comprising:

generating a sensor output signal indicative of the magnetic field output signal.

18. The method of claim 11, wherein the first and second magnetic field sensing elements each comprise one or more Hall effect elements.

19. A magnetic field sensor comprising:

first magnetic field sensing means configured to generate a first magnetic field signal indicative of a magnetic field associated with a target;

second magnetic field sensing means, disposed at a predetermined distance from the first magnetic field sensing means, configured to generate a second magnetic field signal indicative of the magnetic field associated with the target, wherein each of the first and second magnetic field sensing elements has four terminals; and

switching means configured to couple the first magnetic field sensing means and the second magnetic field sensing means in parallel to amplification means, the switching means configured to:

couple a first terminal of the first magnetic field sensing means having a first polarity to a first terminal of the second magnetic field sensing means having a polarity opposite the first polarity to generate a first combined signal;

couple a second terminal of the first magnetic field sensing means having a polarity opposite the first polarity to a second terminal of the second magnetic field sensing means having the first polarity to generate a second combined signal; and

simultaneously couple the first combined signal and the second combined signal to the amplification means, the amplification means configured to generate a magnetic field output signal indicative of a difference between the first combined signal and the second combined signal, wherein the difference is indicative of the magnetic field associated with the target that has stray magnetic field effects cancelled;

wherein the switching module comprises:

a set of four switches for each terminal of the first and second magnetic field sensing elements, each set of four switches configured to selectively couple each terminal to one of a drive input signal having a positive polarity, a drive input signal having a negative polarity, an output signal having a positive polarity, and an output signal having a negative polarity,

wherein, for the first magnetic field sensing element, the first terminal is coupled to the positive polarity drive input signal, the second terminal opposite the first terminal is coupled to the negative polarity drive input signal, a third terminal is coupled to the positive polarity output signal, and a fourth terminal is coupled to the negative polarity output signal, and

wherein, for the second magnetic field sensing element, the first terminal is coupled to the positive polarity drive input signal, the second terminal opposite the first terminal is coupled to the negative polarity drive input signal, a third terminal is coupled to the positive polarity output signal, and a fourth terminal is coupled to the negative polarity output signal.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 11,163,019 B1
APPLICATION NO. : 16/985577
DATED : November 2, 2021
INVENTOR(S) : Virag Chaware et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 13, Line 29 delete “positive of voltage” and replace with --positive voltage--.

In the Claims

Column 17, Line 38 Claim 11 delete “cancelled” and replace with --cancelled;--.

Column 17, Line 56 Claim 11 delete “output signal,” and replace with --drive input signal--.

Signed and Sealed this
Twentieth Day of December, 2022

Katherine Kelly Vidal

Katherine Kelly Vidal
Director of the United States Patent and Trademark Office